Long-term trends in cetacean incidents in New South Wales, Australia

Hannah B. Lloyd & Geoffrey A. Ross*

New South Wales National Parks & Wildlife Service, Office of the Environment & Heritage, P.O. Box 1967 Hurstville, NSW, Australia 1481

*Corresponding author email: Geoff.Ross@environment.nsw.gov.au

ABSTRACT

This study provides an account of cetacean incidents in New South Wales, Australia. Incidents comprise reports of carcasses, injured and debilitated animals found stranded onshore, entrapped in shallow water, entangled or floating offshore. Marine mammal incidents were reported to the New South Wales National Parks and Wildlife Service (NSW NPWS) and recorded into the NSW NPWS Marine Fauna Events Database. Cetacean incident data was used to look for trends in cetacean mortality and debilitation, and baseline information on population dynamics including age and sex ratios. The database contains 891 cetacean records between 1790 and 2013. There were 33 cetacean species reported into the database, consistent with the known species richness of cetaceans in NSW waters. Incidents were categorised into one of 14 types. The cause of mortality or morbidity could not be established for the majority of cases. However, more incidents were related to anthropogenic causes (e.g. entanglements, vessel strike) than natural causes (e.g. disease, calf mortality). The largest known cause of incidents was entangled cetaceans (134 individuals), most of which were Humpback Whales caught in fishing gear. The results of this study highlight the utility of cetacean incident data for monitoring changing population dynamics and quantifying the magnitude of key threatening processes. Improved consistency in reporting over time has greatly improved the value of the database as a conservation monitoring tool.

Key words: marine mammal, cetacean mortality, event, stranding, entanglement, injury, human impact

DOI: http://dx.doi.org/10.7882/AZ.2015.015

Introduction

The conservation of cetaceans is hindered by a paucity of information on the basic demographic and life history traits of many species (Schipper *et al.* 2008; Davidson *et al.* 2012). The lack of information is a consequence of the inherent difficulties in obtaining data on marine mammals (e.g. remote offshore locations, significant research costs, large and highly mobile species, infrequent sightings) (Lewison *et al.* 2004; Leeney *et al.* 2008; Pikesley *et al.* 2011; Davidson *et al.* 2012). Incidents involving cetacean species (e.g. strandings, unusual mortality events) are a valuable source of information for the management of marine mammals (Gulland 2006; Bogomolni *et al.* 2010). Data from strandings are the primary source of biological information for some rare or widely distributed species (e.g. some beaked whales; van Helden *et al.* 2002).

Historical cetacean incident records have provided important baseline information on cetacean populations, such as regional species richness (see Byrd *et al.* 2014), and demographic data (e.g. body size, age structure; Mattson *et al.* 2006). Data collected from wildlife incidents are often used to identify patterns in cetacean mortality and morbidity (Bogomolni *et al.* 2010). For example, Truchon *et al.* (2013) looked at the impacts of climate change on marine mammal survival in Saint Lawrence, Canada, and found that decreasing krill abundance and poor sea ice conditions was correlated with an increase in stranding events in the region. These data can also be used to identify trends in natural causes (e.g. calf mortality, disease and infection) versus anthropogenic causes (e.g. vessel strike, fishing gear entanglements, intentional harm) (Kemper *et al.* 2005). For example, Byrd *et al.* (2014) looked at patterns in marine mammal strandings in North Carolina, USA and found that most anthropogenic related strandings resulted from entanglements and that spatiotemporal trends in strandings of Bottlenose Dolphin *Tursiops* spp. correlated with gillnet fishery activity.

The National Oceanic and Atmospheric Administration, USA, stranding definition includes both live and dead cetaceans found on a beach, entrapped in shallow water, or floating near-shore (Wilkinson 1991; Gulland 2006). In this study, we use the term incident to encompass stranding events, as well as injured, debilitated, and entangled animals. Previous studies on marine mammal incidents have been conducted for most Australian states, including South Australia (Kemper *et al.* 2005), Western Australia (Groom & Coughran 2012a), the Northern Territory (Chatto & Warneke 2000), and Tasmania (MacManus *et al.* 1984; Nicol & Croome 1988). To date there have been no publications for the states of Queensland, Victoria, or New South Wales (NSW), though there have been studies on marine mammal bycatch in shark-mesh nets in NSW and Queensland (Paterson 1990; Krogh & Reid 1996; Gribble 1998). There are databases for cetacean incidents in NSW and Queensland, but the data are not published in peer-reviewed literature (e.g. Meager *et al.* 2012; NSW NPWS 2012).

Thirty-six cetacean species have been sighted in NSW waters (including four unverified species sightings) (Smith *et al.* 2001; NSW NPWS 2002). There are no endemic marine mammals in NSW (Smith *et al.* 2001). Marine mammal species are generally widely distributed and some are migratory. Species encountered in NSW waters are likely to be encountered in other states, as well as national and international waters (Bryden *et al.* 1999; Smith *et al.* 2001). All cetaceans are protected in NSW waters under the *National Parks and Wildlife Act 1974* and in Australian waters under the *Environment Protection and Biodiversity Conservation Act 1999* (Department of the Environment 2014; Smith *et al.* 2001). Four cetacean species are listed as threatened in NSW under the *Threatened Species Conservation Act 1995*, namely the Southern Right Whale *Eubalaena australis* and Blue Whale *Balaenoptera musculus*, which are listed as endangered, and the Sperm Whale *Physeter macrocephalus* and Humpback Whale *Megaptera novaeangliae*, which are listed as vulnerable (Department of the Environment 2014). The Southern Right Whale, Blue Whale, and Humpback Whale are listed as nationally threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (Department of the Environment 2014).

The NSW National Parks and Wildlife Service (NPWS) has statutory responsibility for the protection, conservation and management of marine wildlife, both inside and outside national parks, extending to three nautical miles (5.5 km) offshore (NSW NPWS 2002), and is the lead agency responsible for managing incidents involving cetaceans in NSW. The NSW NPWS Marine Fauna Events Database maintains records of incidents concerning marine fauna species in NSW that required the involvement of the NPWS. The database is a critical source of information for monitoring threatened species' occurrences, changing population dynamics, and anthropogenic threats. The data also support the allocation of resources for emergency response throughout the state by identifying hot-spots for incidents. In this study, we provide the first overview of cetacean incidents in NSW. Our aim is to identify trends in natural and anthropogenic causes of cetacean mortality, morbidity and injury, as well as provide information on spatial and temporal patterns in the presence of species and demography (e.g. sex, age) of cetaceans in NSW.

Methods

Study area

The state of NSW contains 2,137 km of coastline (including 130 km on offshore islands), and extends over nine degrees latitude (from -37.5° to -28.2°) (Geosciences Australia 2004, 2010). The state's marine environment ranges from temperate in the south to subtropical in the north. Tropical temperatures sometimes occur when warm tropical waters extend southward via the East Australian Current (Poloczanska *et al.* 2007). The ocean off the coast of NSW encompasses the southern distribution of tropical species (e.g. Indopacific Humpback Dolphin *Sousa chinensis*; Parra *et al.* 2004), the northern distribution of Antarctic species, and the eastern migration route for Humpback Whales (Bryden *et al.* 1999).

Data collection

The NSW NPWS Marine Fauna Events Database is a record of all marine mammal incidents reported to NPWS that required the involvement of NSW state agency field staff, licensed fauna rehabilitation groups, or occasionally members of the public. NPWS staff may have been called to monitor an animal (e.g. to assess its condition and manage public interaction), assist in the rescue or release of an animal (e.g. disentanglement from fishing gear), provide veterinary advice or assistance (e.g. on intervention, euthanasia, rehabilitation), transport an animal to a rehabilitation facility, or manage an animal carcass (e.g. burial or necropsy).

Data recorded comprises (1) spatial and temporal data, (2) animal details, (3) incident details, and (4) management information. Spatial-temporal data collected comprises the location, date, and time of the incident. There are eight NPWS Regions along the NSW coast that report incidents (Fig. 1). The spatial distribution of fauna incidents was determined based on the number of incidents reported from each Region. To minimise bias from Regions with greater lengths of coastline, we divided the number of incidents in each Region by the kilometres of coastline of each Region (excluding bays and estuaries). Animal data collected included sex (male, female, unknown), status at time of arrival (alive or dead), age category (immature, mature, unknown), size measurements, and species. Bottlenose Dolphins *Tursiops aduncus* and *Tursiops truncatus* were grouped (see Kemper *et al.* 2005; Groom & Coughran 2012a), as these animals are difficult to identify to species and in some cases identification could not be verified. Incident information collected included the incident category, and body condition (e.g. advancement of carcass decomposition). Management information collected included the intervention undertaken (if any), justification for intervention, as well as the outcome of the incident.

Pathology reports, field reports and photographs were used to determine the probable cause of each incident. Incidents were categorised into one of 14 types: ingestion of foreign material; intentional harm; predation; vessel strike; entrapment; disease; injured or debilitated; neonate

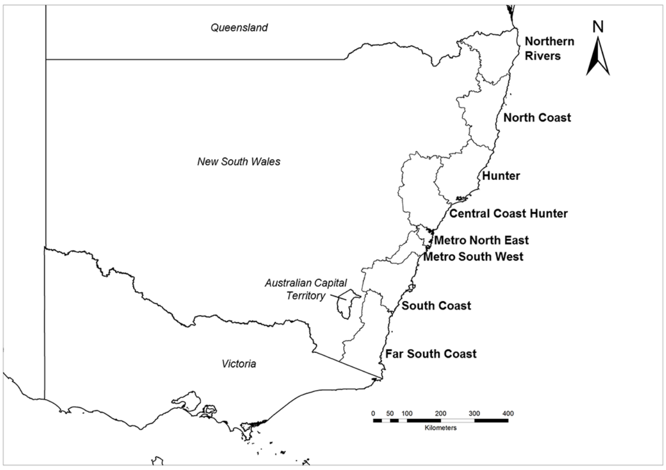

Figure 1. NSW National Parks and Wildlife Service Regions, New South Wales, Australia.

or calf; entanglement in crab-pot; entanglement in net; entanglement in shark-mesh net; entanglement in line or rope; entanglement (other); and undetermined or other. Each record in the database represents an individual animal. In the case of multiple incidents, records were created for each animal involved and are linked to each other. Highly mobile animals may be the subject of more than one incident if observed along different parts of the coastline on different days (e.g. whales trailing fishing gear), though the data are verified to minimise cases when individuals may could be recorded more than once. Although procedures are in place for marine mammal incidents to be reported to NPWS, it is unlikely that all cetacean incidents that have occurred in NSW are present in the database.

Results

The database contains 891 records of cetaceans between 1790 and 2013. There are 21 records prior to 1960; records during this period were from external sources e.g. museum records. Therefore, the majority of records are from the past 50 years. There were 33 species, as well as 58 unidentified cetaceans in the database (Table 1). The most common species encountered were Bottlenose Dolphin and Humpback Whale. Dolphins and small toothed whales comprised 54% of animals, baleen whales made up 22% of animals, toothed whales made up 12% of animals, and beaked whales made up 5% of animals. The remaining 7% were unidentified cetaceans (Table 1). In the majority of cases (62%, n = 555) sex was not able to be determined. Of the remaining individuals, 20% were females (n = 178) and 18% were males (n = 158). Age was not determined for the majority of animals (42%, n = 370). Of the animals whose age class was determined 55% (n = 287) were immature, and 45% (n = 234) were adults.

Most animals were encountered individually (90%, n = 801), with only 10% of incidents involving two or more animals. Of the incidents involving multiple animals, six were calf and dam pairs, one incident involved a pair of males, and eight incidents involved three or more animals, including one mass stranding of 50 False Killer Whales. No species showed a clear tendency towards mass stranding as most species were reported in one multiple stranding incident only. However, Bottlenose Dolphins and Pygmy Sperm Whales were each involved in three single species mass strandings and Blainville's Beaked Whale in two.

Temporal patterns

Over the history of the database, there has been an average of 12.6 incidents per year (± SE 1.8) (excluding a mass stranding of 50 False Killer Whales in 1992). There has been an increase in reports over time with an average of 1.3 incidents reported per year (± SE 0.2) prior to 1960, and an average 43.5 (± SE 5.1) reported per year in the last three years (2010-13) (Fig. 2). Peaks occurred in 1992 and 2009. Seventy-four incidents occurred in 1992, including a mass stranding (n = 50) of False Killer Whales. In 2009, 66 incidents were reported, including one mass stranding of five Bottlenose Dolphins. Baleen Whale incidents peaked between July and October (Fig. 3a), and toothed cetacean incidents peaked in January and July (Fig. 3b) (years pooled).

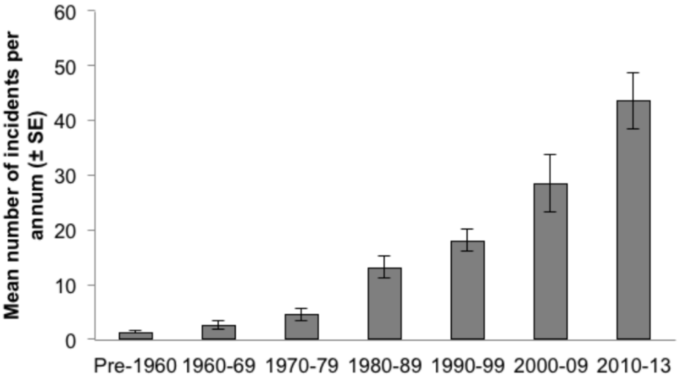

Figure 2. Mean number of cetacean incidents (± SE) per annum for each decade in the NSW database.

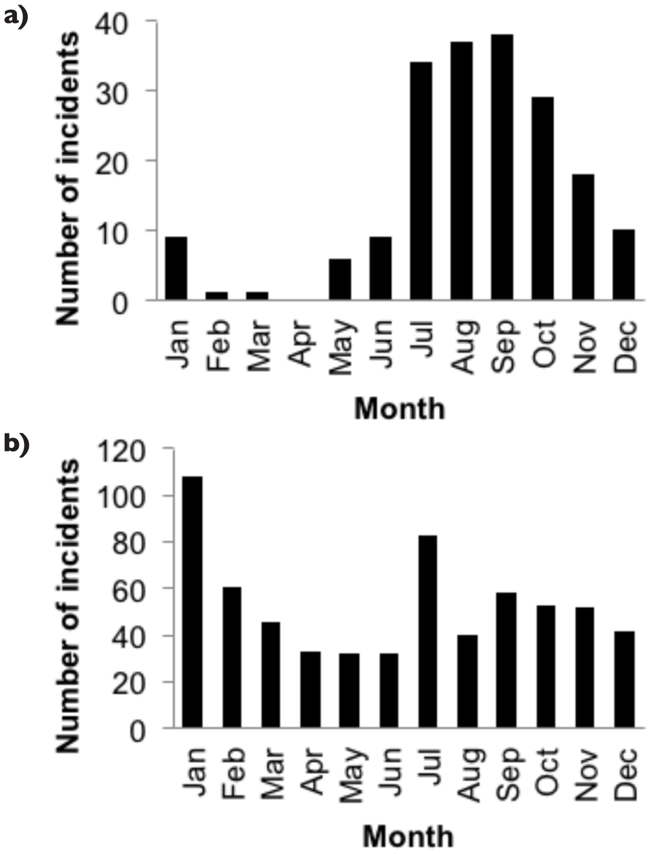

Figure 3. Number of cetacean incidents in each month (years pooled) for (a) baleen whales, and (b) toothed cetaceans in the NSW database.

Spatial patterns

There was a concentration of cetacean incidents in northern NSW including the Northern Rivers (n = 115 incidents) and North Coast (n = 221) Regions. A high number of incidents also occurred in the Hunter Region (n = 161). Similar spatial patterns occurred when taxonomic groups were separated, except beaked whales, which peaked in both the North Coast and South Coast Regions. The distribution pattern of cetacean incidents varied when incidents were divided by the length of coastline within each Region. A higher proportion of incidents per kilometre occurred in the metropolitan areas surrounding Sydney than other Regions (Fig. 4).

Table 1. Number of incidents for each cetacean species reported in NSW from 1790 to 2013.

Common name	Species name	Incidents
Baleen whales (families Balaenopteridae and Balaenidae)		
Humpback Whale	*Megaptera novaeangliae*	156
Minke Whale	*Balaenoptera acutorostrata*	18
Bryde's Whale	*Balaenoptera edeni*	10
Southern Right Whale	*Eubalaena australis*	7
Blue Whale	*Balaenoptera musculus*	2
Total baleen whales		193
Beaked whales (family Ziphiidae)		
Strap-toothed Beaked Whale	*Mesoplodon layardii*	14
Blainville's Beaked Whale	*Mesoplodon densirostris*	12
Gray's Beaked Whale	*Mesoplodon grayi*	9
Andrew's Beaked Whale	*Mesoplodon bowdoini*	4
Ginkgo-toothed Beaked Whale	*Mesoplodon ginkgodens*	4
Cuvier's Beaked Whale	*Ziphius cavirostris*	2
Southern Bottlenose Whale	*Hyperoodon planifrons*	1
Total beaked whales		46
Toothed whales (families Kogiidae and Physeteridae)		
Pygmy Sperm Whale	*Kogia breviceps*	70
Sperm Whale	*Physeter macrocephalus*	35
Dwarf Sperm Whale	*Kogia simus*	4
Total toothed whales		109
Dolphins and small toothed whales (family Delphinidae)		
Bottlenose Dolphin	*Tursiops spp.*	171
Common Dolphin	*Delphinus delphis*	91
False Killer Whale	*Pseudorca crassidens*	65
Risso's Dolphin	*Grampus griseus*	34
Melon-headed Whale	*Peponocephala electra*	31
Short-finned Pilot Whale	*Globicephala macrorhynchus*	20
Striped Dolphin	*Stenella coeruleoalba*	20
Pygmy Killer Whale	*Feresa attenuata*	12
Pantropical Spotted Dolphin	*Stenella attenuata*	11
Fraser's Dolphin	*Lagenodelphis hosei*	6
Long-finned Pilot Whale	*Globicephala melas*	6
Killer Whale (Orca)	*Orcinus orca*	5
Spinner Dolphin	*Stenella longirostris*	5
Indopacific Humpbacked Dolphin	*Sousa chinensis*	3
Pygmy Right Whale	*Caperea marginata*	2
Dusky Dolphin	*Lagenorhynchus obscurus*	1
Rough-toothed Dolphin	*Steno bredanensis*	1
Southern Right Whale Dolphin	*Lissodelphis peronii*	1
Total dolphins		485
Other		
Unidentified cetacean		58
Total		**891**

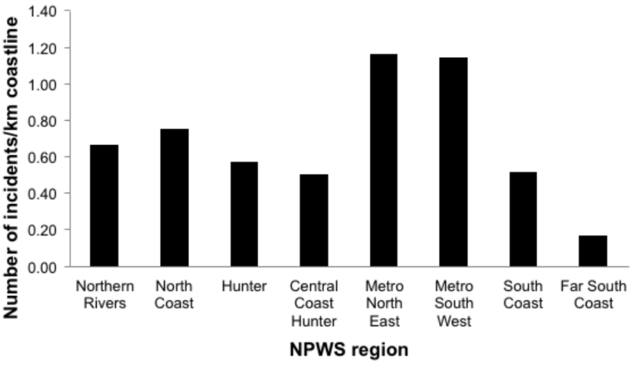

Figure 4. Number of cetacean incidents reported in each NPWS region (north to south) in the NSW database, divided by the length of coastline of each region.

Cause of incidents

The majority of animals were found dead (n = 488, 55%) (e.g. Fig. 5), one-third of animal's were found alive (n = 312, 35%) (including animals that subsequently died), and for 10% of cases the animal status was not reported. Cause of death could not be determined for 65% of incidents and there was no evidence to indicate whether 67% were natural or human related. Direct anthropogenic impacts (entanglements, vessel strike, ingestion of foreign material, intentional harm) were identified for 19% of incidents (Fig. 6). Natural incidents (disease, entrapment, predation, neonate mortality) made up 14% of cases (Fig. 6). Injured or debilitated animals occurred from a range of causes including human impact (e.g. entanglement scars) and natural circumstances (e.g. emaciation, conspecific attack). Entanglements in commercial fishing lines, ropes (Fig. 7), nets, and crab-pots were the greatest known cause of incidents overall, comprising 42% of incidents where an incident category was established (Fig. 6 and 8).

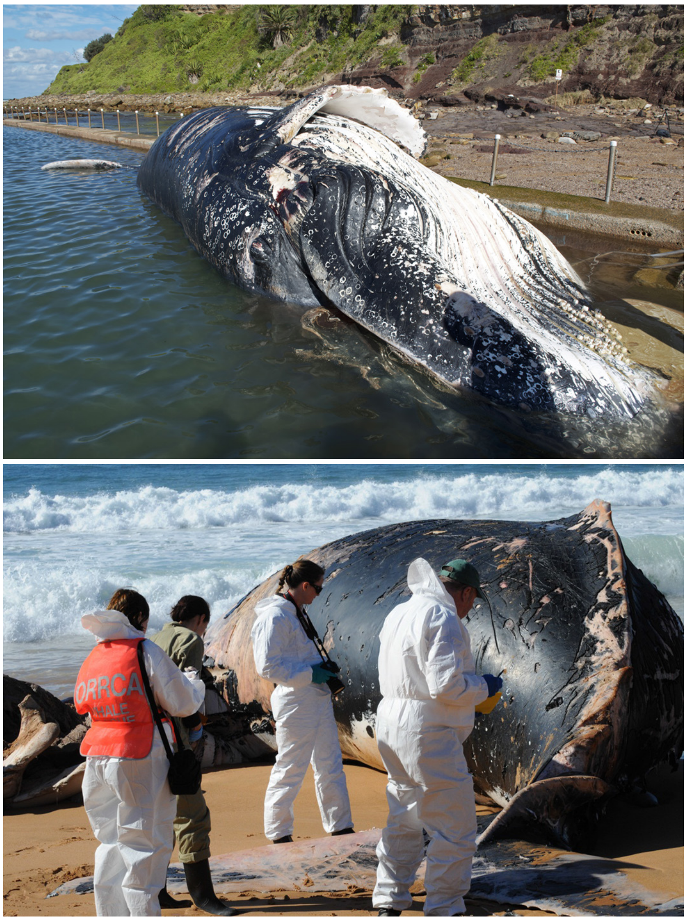

Figure 5. Beach-washed Humpback Whale carcass, Newport Beach, NSW, 1 August 2012. Top picture: Whale carcass washed into ocean pool. Bottom picture: NPWS, Taronga Zoo and ORRCA investigate the animal's cause of death. Photos by S. Cohen and G. Ross NPWS.

Discussion

Previous papers have shown that the species richness reported in cetacean stranding data is generally consistent with the species richness of wild cetacean populations (Maldini *et al.* 2005; Pikesley *et al.* 2011; Groom and Coughran 2012a). All cetacean species known to occur in NSW waters were recorded in our database (excluding unconfirmed species sightings) (Smith *et al.* 2001). Bottlenose Dolphins and Humpback Whales were the most common species reported. Bottlenose Dolphins are commonly sighted in NSW and have several breeding populations off the NSW coast (Smith *et al.* 2001). Humpback Whales are seen in high numbers during their annual migration between

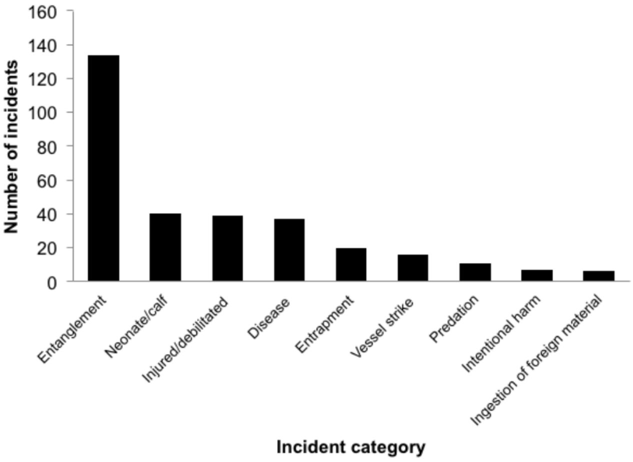

Figure 6. Number of incidents in each category in the NSW database (excluding the category 'undetermined/other').

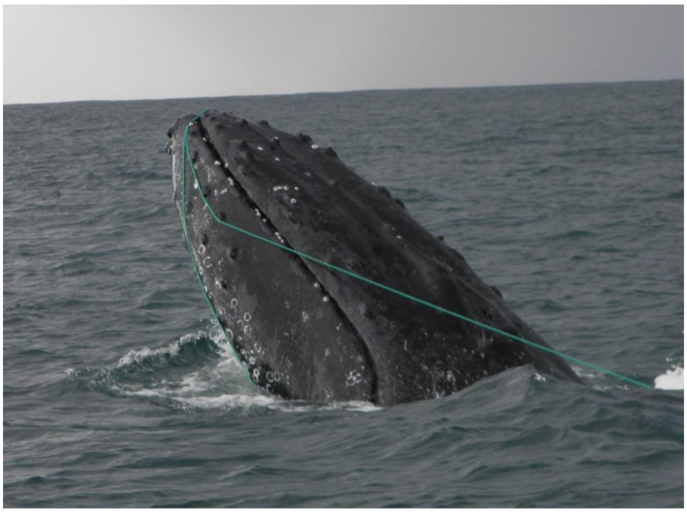

Figure 7. Humpback Whale caught in commercial fishing tackle, Tacking Point, NSW, 2011. Photo by Cruise Adventures Port Macquarie.

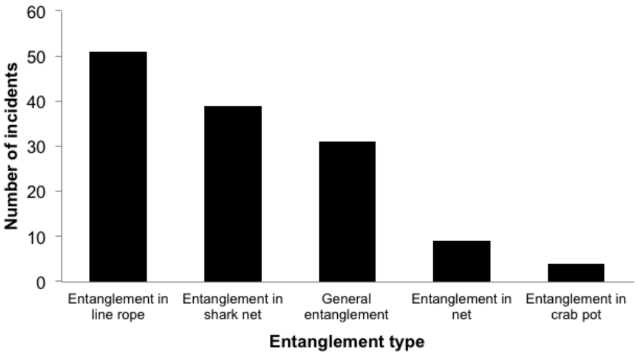

Figure 8. Number and type of entanglements reported in the NSW database.

Antarctic feeding grounds and tropical breeding grounds (Noad *et al.* 2006). Delphinidae was the most commonly reported cetacean family. Delphinidae is a diverse and abundant cetacean group that comprises all dolphins (i.e. small toothed cetaceans). The second most abundant group was baleen whales; predominantly migrating Humpback Whales (Noad *et al.* 2006). Toothed whales, including Sperm Whales, Pygmy Sperm Whales and Dwarf Sperm Whales were not frequently reported, presumably because they are relatively uncommon and Sperm Whales populations are still recovering post-exploitation (IUCN 2013, Carroll *et al.* 2014). The group with the lowest number of incidents was beaked whales, all of which are rare and inconspicuous (IUCN 2013).

There were no clear patterns in the sex of species involved in incidents. Norman *et al.* 2004 also found no clear patterns in the sex of stranded cetaceans in the North West Region Strandings database in the USA. There were slightly more incidents involving immature cetaceans than mature cetaceans. A higher incident rate of immature cetaceans is consistent with the high natural mortality rates of cetacean calves (Mann *et al.* 2000; Kemper *et al.* 2005; Groom and Coughran 2012a). There were only eight mass stranding events (involving 3 or more individuals). Mass stranding events are sometimes attributed to the coastal topography of the area, or proximity to naval bases, and are more common further south in Tasmania and Victoria (Bradshaw *et al.* 2006).

Temporal patterns

The increase in incidents reported into the database over time may be partly due to increasing cetacean populations' post commercial whaling. The trend is stronger than expected based on population recovery alone (Noad *et al.* 2006) and is probably a reflection of improved reporting over time. Improved reporting of cetacean incidents has been observed worldwide, resulting from growing global interest in cetaceans (Norman *et al.* 2004; Leeney *et al.* 2008; Groom and Coughran 2012a). Seasonal patterns in baleen whale incidents corresponded with the annual Humpback Whale migration (Noad *et al.* 2006). The peak of toothed cetacean incidents in summer was presumably a result of greater interactions between coastal cetaceans and humans during this time; including increased observers, higher recreational vessel traffic and deployment of shark-mesh nets (Krough and Reid 1996; Norman *et al.* 2004). The peak in July was an artefact of a mass stranding of 50 False Killer Whales in July 1992.

Spatial patterns

Spatial patterns in cetacean incidents reflect the natural distribution of cetacean species, reporting effort, accessibility of the coast, and density of the human population (Norman *et al.* 2004; Nemiroff *et al.* 2010). When corrected for the length of coastline, the distribution of incidents reflected the density of the human population, with high numbers of incidents in metropolitan areas surrounding Sydney and low numbers on the Far South Coast (Australian Bureau of Statistics 2014) where much of the coastline is remote and inaccessible. Correlations between cetacean incidents and human population density have similarly been seen in other studies, and attributed to a greater number of observers in populated areas (see Norman *et al.* 2004; Groom and Coughran 2012a).

Cause of incidents

It was difficult to determine the cause of death for a large proportion of animals, particularly as many were probably dead before washing ashore. Of those incidents where cause of death was determined, more were related to anthropogenic impacts than natural circumstances. Incidents involving neonates or calves were common, and stranded or washed ashore with no signs of injury. A substantial number of natural incidents were also linked to disease. However, there were no cases of mass mortality or severe disease outbreaks reported. Anthropogenic impacts were only identified in cases where the cause of the incident was clear, such as lacerations related to vessel strike (Fig. 9), or plastic ingestion determined from necropsy. As necropsies were only conducted for a small percentage of cases, the actual impacts of vessel strike and ingestion of marine debris are likely to be underestimated.

Entanglements were the greatest known cause of cetacean incidents. Entanglement of cetaceans as bycatch or in marine debris is widely recognised as one of the key threats to cetaceans globally (Read *et al.* 2006; Leeney *et al.* 2008; Benjamins *et al.* 2012). The majority of entangled animals were Humpback Whales caught in fishing gear (Fig. 10). NPWS has trained disengagement teams to respond to such incidents, and both successful and attempted disentanglements are reported. Groom and Coughran (2012b) also reported a high occurrence of Humpback Whales entangled in fishing gear on the west coast of Australia. Humpback Whales are susceptible to entanglement because of their near-shore migration path, and such entanglements are expected to increase further as Humpback Whale populations continue to recover (Groom and Coughran 2012b).

Many animals were entangled in shark-mesh nets, set to protect bathers. Shark-mesh nets have been used in NSW since 1937 and are used at 51 beaches between September 1st and April 30th each year (NSW DPI 2009). Previous studies reported higher numbers of shark-mesh net entanglements in NSW than our database shows. The studies reported 95 cetaceans

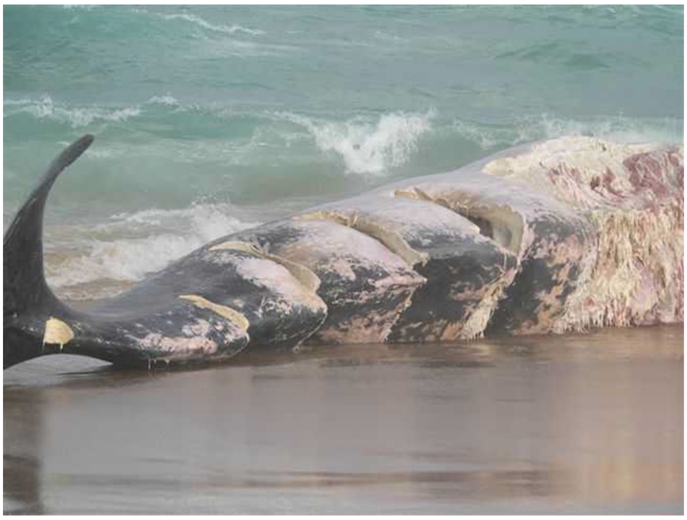

Figure 9. Sperm Whale carcass with deep propeller cuts from vessel strike, Dixon Park Beach, NSW, 7 August 2006. Photo by NPWS.

between 1950 and 1993 (Krough and Reid 1996) and 49 dolphins between 1994 and 2009 (Green *et al.* 2009); suggesting a level of underreporting in our data. High numbers of cetacean mortality have been reported from Queensland shark-mesh nets with an average of ten entanglements reported each year (Gribble *et al.* 1998). Mitigation measures have been put in place in NSW to minimise marine mammal bycatch in shark-mesh nets. The measures include removing nets during winter, not setting nets at the surface of the water, and fitting whale alarms and acoustic 'pinger' devices to deter both baleen and toothed cetaceans (NSW DPI 2009). However, a dead Common Dolphin *Delphinus delphis* was found entangled next to an acoustic pinger device. Therefore, we recommend that further research be conducted on the effectiveness of these mitigation measures to ensure bycatch continues to decline in the future.

Stranding and incident records have shown to be a good reflection of the composition of natural cetacean populations (see Groom and Coughran 2012a; Byrd et al. 2014). However, the limitations of strandings data for identifying trends in population processes are widely recognised (Norman et al. 2004; Nemiroff et al. 2010). For example, the inconsistency in spatial and temporal data due to variability in reporting effort and numbers of observers, and the influence of oceanography (i.e. currents, wind) on stranding patterns (Nemiroff et al. 2010; Peltier et al. 2012). Identifying mortality trends has an inherent bias towards obvious causes of mortality (e.g. predation, injury, entanglement) over less obvious causes (e.g. disease, ingestion of marine debris) (Kemper et al. 2005). Necropsies have proven highly valuable for establishing the cause of death of cetacean incidents in NSW. Increasing the number of necropsies performed will greatly improve our understanding of the threats to marine mammal conservation in NSW, particularly for causes that are difficult to detect e.g. ingestion of marine debris. Underreporting reduces the usefulness of the database to inform management decisions regarding the conservation of cetaceans in NSW. Improved reporting procedures, including better communication within and between the relevant organisations (i.e. NSW state agencies, fauna rehabilitation groups) will greatly improve the value of the database as a conservation monitoring tool. The results of this study highlight the significance of anthropogenic threats to cetaceans in NSW and the need to implement mitigation measures to reduce the impact of key threatening processes (e.g. entanglement). Along with current disentanglement operations, the development of fishing practices that minimise entanglement risk, as well as efforts to manage marine debris (e.g. ghost fishing gear) (Bogomolni et al. 2010) will help to improve the conservation status of cetaceans in NSW.

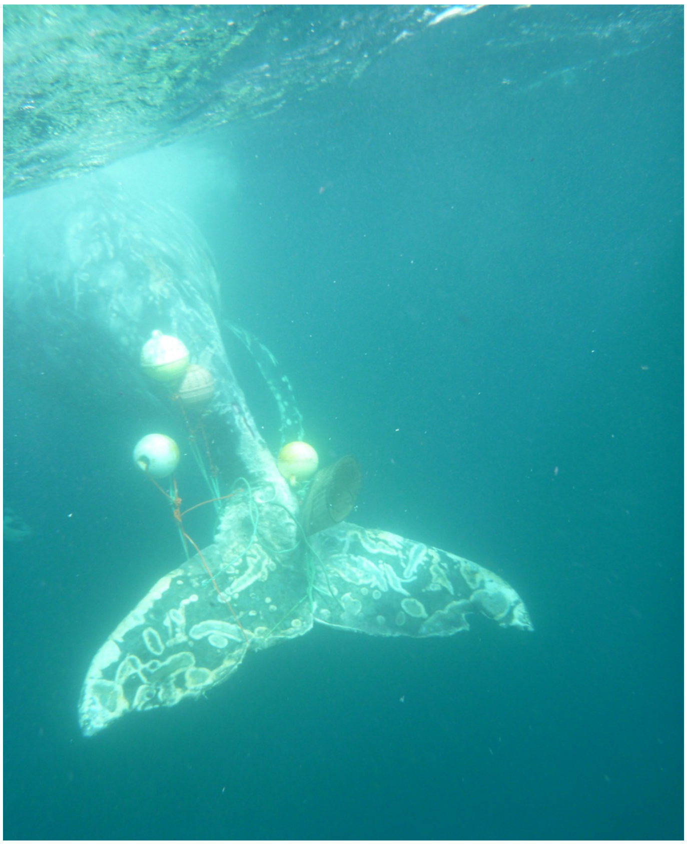

Figure 10. Humpback Whale caught in fishing gear, Seven Mile Beach, NSW, 6 July 2011. The whale was entangled around its tail and mouth in buoys, rope and steel canister. The animal was disentangled by NPWS staff. Photo by David Bearup NPWS.

Acknowledgements

We acknowledge the NPWS staff that attended marine incidents and provided most of the data. We thank the Taronga Conservation Society and Wildlife Health Australia for veterinary and pathology support, in particular Dr. Karrie Rose for her ongoing support. We thank private veterinarians and rehabilitation groups in particular ORRCA and Dolphin Marine Magic, who attended many incidents. Thank you Chris Togher and Gareth Evans of NPWS for providing GIS support. Thank you to Dr. Sue Briggs and Dr. David Priddel of NPWS for comments on the manuscript.

References

Australian Bureau of Statistics. 2014. Australian Population Grid 2011, data cube, cat. no. 1270.0.55.007. Available from: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/1270.0.55.007Main+Features12011?OpenDocument (accessed April 2015).

Benjamins, S., Ledwell, W., Huntington, J. and Davidson, A.R. 2012. Assessing changes in numbers and distribution of large whale entanglements in Newfoundland and Labrador, Canada. *Marine Mammal Science*. **28:** 579-601. http://dx.doi.org/10.1111/j.1748-7692.2011.00511.x

Bogomolni, A.L., Pugliares, K.R., Sharp, S.M., Patchett, K., Harry, C.T., LaRocque, J.M., Touhey, K.M. and Moore, M.J. 2010. Mortality trends of stranded marine mammals on Cape Cod and southeastern Massachusetts, USA, 2000 to 2006. *Diseases of Aquatic Organisms*. **88:** 143-155. http://dx.doi.org/10.3354/dao02146

Bradshaw, C.J., Evans, K. and Hindell, M.A. 2006. Mass cetacean strandings – a plea for empiricism. *Conservation Biology*. **20**: 584-586. http://dx.doi.org/10.1111/j.1523-1739.2006.00329.x

Bryden, M., Marsh, H. and Shaughnessey, P. 1999. *Dugongs, Whales, Dolphins and Seals: A Guide to the Sea Mammals of Australasia.* Allen & Unwin, Sydney, Australia.

Byrd, B.L., Harms, C.A., Hohn, A.A., McLellan, W.A., Lovewell, G.N., Moore, K.T., Altman, K.M., Rosel, P.E., Barco, S.G., Thayer, V.G. and Friedlaender, A. 2013. Strandings as indicators of marine mammal biodiversity and human interactions off the coast of North Carolina. *Fishery Bulletin*. **1:** 1-23. http://dx.doi.org/10.7755/FB.112.1.1

Carroll, G., Hedley, S., Bannister, J., Ensor, P, and Harcourt, R. No evidence for recovery in the population of sperm whale bulls off Western Australia, 30 years post-whaling. *Endangered Species Research*. **24:** 33-43. http://dx.doi.org/10.3354/esr00584

Chatto, R. and Warneke, R.M. 2000. Records of cetacean strandings in the Northern Territory of Australia. *The Beagle: Records of the Museums and Art Galleries of the Northern Territory.* **16**: 163-175.

Davidson, A.D., Boyer, A.G., Kim, H., Pompa-Mansilla, S., Hamilton, M.J., Costa, D.P., Ceballos, G. and Brown, J.H. 2012. Drivers and hotspots of extinction risk in marine mammals. *Proceedings of the National Academy of Sciences*. **9:** 3395-3400. http://dx.doi.org/10.1073/pnas.1121469109

Department of the Environment. 2014. Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat (accessed July 2014).

Geoscience Australia. 2004. GEODATA Coast 100K 2004. Available from: http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_61395 (accessed April 2014).

Geoscience Australia. 2010. Coastline Lengths. Available from: http://www.ga.gov.au/education/geoscience-basics/dimensions/coastline-lengths.html/ (accessed April 2014).

Green, M., Ganassin, C. and Reid, D.D. 2009. *Report into the NSW Shark Meshing (Bather Protection) Program.* NSW Department of Primary Industries, New South Wales, Australia.

Gribble, N.A., McPherson, G. and Lane, B. 1998. Effect of the Queensland shark control program on non-target species: whale, dugong, turtle and dolphin: a review. *Marine and Freshwater Research.* **49**: 645—651. http://dx.doi.org/10.1071/MF97053

Groom, C.J., and Coughran, D.K. 2012a. Three decades of cetacean strandings in Western Australia: 1981 to 2010. *Journal of the Royal Society of Western Australia.* **95**: 63–76.

Groom, C.J., and Coughran, D.K. 2012b. Entanglements of baleen whales off the coast of Western Australia between 1982 and 2010: patterns of occurrence, outcomes and management responses. *Pacific Conservation Biology*. **18:** 203-214.

Gulland, F.M.D. 2006. *Review of the Marine Mammal Unusual Mortality Event Response Program of the National Marine Fisheries Service.* U.S. Department of Commerce, NOAA Technical Memo, USA.

IUCN. 2013. IUCN Red List of Threatened Species. Version 2013.2. Available from: www.iucnredlist.org (accessed May 2014).

Kemper C.M., Flaherty A., Gibbs S.E., Hill M., Long M. and Byard R.W. 2005. Cetacean captures, strandings and mortalities in South Australia 1881—2000, with special reference to human interactions. *Australian Mammalogy.* **27:** 37-47.

Krough, M. and Reid, D. 1996. Bycatch in the protective shark meshing programme off south-eastern New South Wales, Australia. *Biological Conservation.* **77**: 219—226. http://dx.doi.org/10.1016/0006-3207(95)00141-7

Leeney, R.H., Amies, R., Broderick, A.C., Witt, M.J., Loveridge, J., Doyle, J. and Godley, B.J. 2008. Spatio-temporal analysis of cetacean strandings and bycatch in a UK fisheries hotspot. *Biodiversity and Conservation* **17:** 2323-2338. http://dx.doi.org/10.1007/s10531-008-9377-5

Lewison, R.L., Crowder, L.B., Read, A. and Freeman, S.A. 2004. Understanding the impacts of fisheries bycatch on marine megafauna. *TRENDS in Ecology and Evolution.* **19:** 598-604. http://dx.doi.org/10.1016/j.tree.2004.09.004

Maldini, D., Mazzuca, L. and Atkinson, S. 2005. Odontocete stranding patterns in the main Hawaiian islands (1937-2002): How do they compare with live animal surveys? *Pacific Science*. **59:** 55-67. http://dx.doi.org/10.1353/psc.2005.0009

Mann, J., Connor, R.C., Barre, L.M. and Heithaus, M.R. 2000. Female reproductive success in bottlenose dolphins (*Tursiops* sp.): life history, habitat, provisioning, and group-size effects. *Behavioral Ecology*. **11**: 210-219. http://dx.doi.org/10.1093/beheco/11.2.210

Mattson, M.C., Mullin, K.D., Ingram, G.W. and Hoggard, W. 2006. Age structure and growth of the bottlenose dolphin (*Tursiops truncates*) from strandings in the Mississippi Sound region of the North Central Gulf of Mexico from 1986 to 2003. *Marine Mammal Science*. **22:** 654-666. http://dx.doi.org/10.1111/j.1748-7692.2006.00057.x

McManus, T.J., Wapstra, J.E., Guiler, E.R., Munday, B.L. and Obendorf, D.L. 1984. Cetacean strandings in Tasmania from February 1978 to May 1983. *Papers and Proceedings of the Royal Society of Tasmania.* **118**: 117—135.

Meager, J.J., Winter, K.M., Biddle, T.M. and Limpus, C.J. 2012. *Marine wildlife stranding and mortality database annual report 2008-2010. II. Cetacean and Pinniped.* Department of Environment and Heritage Protection, Western Australia, Australia.

Nemiroff, L., Wimmer, T., Daoust, P.Y. and McAlpine, D.F. 2010. Cetacean Strandings in the Canadian Maritime Provinces, 1990-2008. *The Canadian Field-Naturalist*. **124:** 32-44.

Nicol, D.J. and Croome, R.L. 1988. Trends in the Tasmanian cetacean stranding record. *Marine mammals of Australasia, field biology and captive management*. 59-70.

Noad, M.J., Paton, D. and Cato, D.H. 2006. Absolute and relative abundance estimates of Australian east coast humpback whales (*Megaptera novaeangliae*). *Journal of Cetacean Research and Management (Special Issue)*. 3: 243-252.

Norman, S.A., Bowlby, C.E., Brancato, M.S., Calambokidis, J., Duffield, D., Gearin, P.J., Gornall, T.A., Gosho, M.E., Hanson, B., Hodder, J., Jeffries, S.J., Lagerquist, B., Lambourn, D.M., Mate, B., Norberg, B., Osborne, R.W., Rash, J.A., Riemer, S. and Scordino, J. 2004. Cetacean strandings in Oregon and Washington between 1930 and 2002. *Journal of Cetacean Research and Management*. **6**: 87-100.

NSW DPI. 2009. *Joint Management Agreement for NSW Shark Meshing (Bather Protection) Program.* NSW Department of Primary Industries, New South Wales, Australia.

NSW NPWS. 2002. *NPWS Policy on Cetacean Conservation and Management.* NSW National Parks and Wildlife Service, New South Wales, Australia.

NSW NPWS. 2012. *Summary of New South Wales Marine Fauna Events: 2010 to 2011.* NSW National Parks and Wildlife Service, New South Wales, Australia.

Parra, G.J., Corkeron, P.J. and Marsh, H. 2004. The Indo-Pacific Humpback Dolphin, *Sousa chinensis* (Osbeck, 1765), in Australian Waters: A Summary of Current Knowledge. *Aquatic Mammals*. **30**: 197-206. http://dx.doi.org/10.1578/AM.30.1.2004.197

Paterson, R.A. 1990. Effects of long-term anti-shark measures on target and non-target species in Queensland, Australia. *Biological Conservation.* **52**: 147−159. http://dx.doi.org/10.1016/0006-3207(90)90123-7

Peltier, H., Dabin, W., Daniel, P., Van Canneyt, O., Dorémus, G., Huon, M. and Ridoux, V. 2012. The significance of stranding data as indicators of cetacean populations at sea: Modelling the drift of cetacean carcasses. *Ecological Indicators*. **18:** 278-290. http://dx.doi.org/10.1016/j.ecolind.2011.11.014

Pikesley, S.K., Witt, M.J., Hardy, T., Loveridge, J., Williams, R. and Godley, B.J. 2011. Cetacean sightings and strandings: evidence for spatial and temporal trends. *Journal of the Marine Biological Association of the United Kingdom.* **1:** 1-12. http://dx.doi.org/10.1017/S0025315411000464

Poloczanska, E.S., Babcock, R.C., Butler, A., Hobday, A.J., Hoegh-Guldberg, O., Kunz, T.J., Matear, R., Milton, D.A., Okey, T.A. and Richardson, A.J. 2007. Climate change and Australian marine life. *Oceanography and Marine Biology.* **45:** 407.

Read, A.J., Drinker, P. and Northridge, S. 2006. Bycatch of marine mammals in U.S. and global fisheries. *Conservation Biology.* **20:** 163–169. http://dx.doi.org/10.1111/j.1523-1739.2006.00338.x

Schipper, J., Chanson, J.S., Chiozza, F., Cox, N.A., Hoffmann, M., Katariya, V., Lamoreux, J., Rodrigues, A.S.L., Stuart, S.N. Temple, H J., et al. 2008. The status of the world's land and marine mammals: diversity, threat, and knowledge. *Science.* **322:** 225-230. http://dx.doi.org/10.1126/science.1165115

Smith, P.J. 2001. *Review of the Conservation Status of Marine Mammal Species in NSW. A report to the NSW Scientific Committee.* NSW National Parks and Wildlife Service, New South Wales, Australia.

Truchon, M.H., Measures, L., L'Hérault, V., Brêthes, J.C., Galbraith, P.S., Harvey, M., Lessard, S., Starr, M. and Lecomte, N. 2013. Marine Mammal Strandings and Environmental Changes: A 15-Year Study in the St. Lawrence Ecosystem. *PLOS ONE.* **8:** 1-10. http://dx.doi.org/10.1371/journal.pone.0059311

Wilkinson, D.M. 1991. *Program review of the marine mammal stranding networks. Report to Assistant Administrator for Fisheries.* NOAA, USA.

van Helden, A.L., Baker, A.N., Dalebout, M.L., Reyes, J.C., van Waerebeek, K. and Baker, C.S. 2002. Resurrection of *Mesoplodon traversii* (Gray, 1874), senior synonym of *M. bahamondi* Reyes, van Waerebeek, Cardenas and Yanez, 1995 (Cetacea: Ziphiidae). *Marine Mammal Science.* **18:** 609–621. http://dx.doi.org/10.1111/j.1748-7692.2002.tb01062.x